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Manual reaction time (RT) responses were analyzed from seven human subjects. Responses were recorded using four kinds of target presentations: fixed visual target, moving visual target, fixed auditory target, and moving auditory target. Moving targets (moving in the horizontal plane) were presented at constant intensity and provided only a motion cue. Fixed targets "popped on" at the primary position and provided only an onset cue. RTs for the fixed and moving visual targets were 241.5 ms and 233.1 ms, respectively. The 8.4 ms advantage for the moving visual target was statistically significant,  $P < .05$ . RT for the moving auditory target varied with target movement amplitude and ranged from 219 ms for 40° movements to 268 ms for 5° movements. For the fixed auditory target, average RT was 182.9 ms. Thus, sound-source motion detection was from 36 to 85 ms slower than sound onset detection,  $P < .001$ .

In an earlier study, saccade latency was measured while subjects visually tracked the same moving targets used in the RT study. For small target displacements, saccade latencies for the moving auditory target were longer than for the moving visual target. The longer latencies for the moving auditory target are attributed to the increased processing time required to detect the sound-source motion.

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# Relationships between Manual Reaction Time and Saccade Latency in Response to Visual and Auditory Stimuli

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ENGELKEN EJ, STEVENS KW, ENDERLE JD. *Relationships between manual reaction time and saccade latency in response to visual and auditory stimuli*. Aviat. Space Environ. Med. 1991; 62:315-8.

Manual reaction time (RT) responses were analyzed from seven human subjects. Responses were recorded using four kinds of target presentations: fixed visual target, moving visual target, fixed auditory target, and moving auditory target. Moving targets (moving in the horizontal plane) were presented at constant intensity and provided only a motion cue. Fixed targets "popped on" at the primary position and provided only an onset cue. RTs for the fixed and moving visual targets were 241.5 ms and 233.1 ms, respectively. The 8.4 ms (3.5%) advantage for the moving visual target over the fixed visual target was statistically significant,  $p < 0.05$ . RT for the moving auditory target varied with target movement amplitude and ranged from 219 ms for 40° movements to 268 ms for 5° movements. For the fixed auditory target in the sagittal plane, average RT was 182.9 ms. Thus, sound-source motion detection was from 36 to 85 ms slower than sound onset detection,  $p < 0.001$ . The RT results were compared to saccade latency measurements from an earlier study. Both RT and saccade latency showed the same dependency upon target movement amplitude. For small target displacements, saccade latencies for the moving auditory target were longer than for the moving visual target. The longer latencies for the moving auditory target are attributed to the increased processing time required to detect the sound-source motion.

**I**N an earlier study we examined voluntary saccadic eye movements made while tracking stepwise moving visual, auditory, and bisensory targets (3). We reported that saccade latency decreased as target displacement increased when tracking auditory targets. Also, for small target displacements, saccades to auditory targets exhibited much longer latency than saccades to visual

targets. Previous studies by Zahn *et al.* (12,13) and Zambarbieri *et al.* (14,15) likewise reported these findings. These authors also noted that, for simple key-pressing tasks, manual reaction times (RTs) were always shorter for auditory stimuli than for visual. This well-known result is generally ascribed to the fact that the transduction process in the retina is 30-50 ms longer than for the ear. The observation that saccade latency is shorter for visual stimuli while RT is shorter for auditory stimuli demanded an explanation. Zahn *et al.* attempted to explain this ambiguity based on the need to remap auditory localization information obtained in craniotopic coordinates into a retinotopic system in order to execute eye movements; visual target information is already in retinotopic coordinates. This remapping was thought to increase the processing time needed to program the auditory saccades. It was this increased processing time that was assumed to be responsible for increasing saccade latency for auditory targets. Since that time, considerable evidence has accumulated indicating that this coordinate remapping does not take place, and so this explanation must be abandoned (4-6,11). Zambarbieri *et al.* postulated that auditory saccades had longer latency because of the "uncertainty" of the auditory localization information. In this model, it is assumed that some "certainty" threshold must be exceeded to trigger a saccade, and auditory information requires more processing time to reach the threshold. Latency is assumed to be longer for small target displacements near the midline because uncertainty is greater there. These authors state:

As a matter of fact, when the source of sound is placed near the midline, the phase and amplitude differences at the level of the subject's ears are very small and the estimate of the absolute values could consequently be more difficult. The longer time needed for processing auditory spatial information would reverse the relationship observed between RTs of auditory and visual responses. . . . The exponential decrease of latency of auditory responses with target eccentricity would be perfectly consistent with the hypothesis of a higher level of uncertainty for smaller eccentricities. . . .

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This hypothesis is flawed. Although the interaural time and intensity differences are smallest at the midline, the rate of change of these differences with respect to target movement is greatest there. As demonstrated by Mills (9), the minimum audible angle (smallest angle of motion detectable) is smallest at the midline and increases with target eccentricity. Therefore, targets moving near the midline should be localized with greater certainty. Thus, under the 'uncertainty' hypothesis, latency should increase with increasing target displacement from the midline, not decrease as it actually does.

The present study was conducted to resolve the RT-saccade latency ambiguity. An experiment was designed to test the hypothesis that sound-source motion detection requires more sensory processing time than the detection of sound onset. Once this hypothesis is established, the previously reported results can be explained on the basis of the auditory cues used to make the responses.

## METHODS AND MATERIALS

**Subjects:** Seven of the eight subjects used in our previous saccadic tracking study participated in this experiment (3). All subjects' vision was at least 6/6 or correctable to 6/6 using contact lenses, and all had normal auditory function.

**Apparatus:** All target presentations were made using the same PDP-11/34 computer controlled apparatus employed in our previous study (3). The reader is referred to this earlier paper for details; the apparatus will be only briefly discussed here.

Nine visual and auditory targets were placed at 5° intervals along a horizontal arc of radius 2 m. The subject's head was positioned at the center of radius of the display with the center target located in the sagittal plane. The subject's head was stabilized using a dental impression bite bar. The visual targets were green (565 nm) light-emitting diodes (LEDs). The auditory targets were provided by 10-cm diameter loudspeakers located behind the LEDs. The targets were covered by a translucent cloth screen so the loudspeakers and extinguished LEDs could not be seen by the subject.

Visual target motion was obtained by extinguishing one LED while simultaneously illuminating another. This provided a constant intensity "jumping" visual target. Sound motion was obtained by electronically switching a band-limited (1–2 kHz) noise signal from one loudspeaker to another. Sounds were presented at 65 dB SPL. To avoid sound onset cues, the switching circuit was designed to "ramp" the sound level down in one loudspeaker and simultaneously ramp the level up in the other. Using a ramp time of 2 ms eliminated any perceived click as the sound moved. This switching method permitted target movement while maintaining constant stimulus intensity.

Manual RT responses were made using an ordinary telegraph key. The key closures completed an electrical circuit that applied a 5-V signal to the A/D converter in the PDP-11/34 computer system. The A/D sampling rate was 1 kHz, providing RT measurements with a resolution of 1 ms.

**Response Conditions:** Subjects were tested under

four stimulus conditions and RT responses were recorded. Each condition consisted of the presentation of a different kind of target. The targets were:

**MVT—Moving Visual Target.** Subjects responded to each visual target movement by pressing a telegraph key as quickly as possible each time the target moved.

**MAT—Moving Auditory Target.** Subjects responded each time the sound moved. Subjects received only a sound-source movement cue.

**FVT—Fixed Visual Target.** Subjects responded each time the center LED in the display was illuminated.

**FAT—Fixed Auditory Target.** Subjects responded each time the center loudspeaker was sounded. Subjects received only a sound-onset cue.

Testing under each condition consisted of having the subjects press the telegraph key as quickly as possible in response to each of 80 target presentations. For the moving-target conditions each presentation consisted of one target movement. The target started in the center position, then moved to one of the other eight positions (with equal probability), then randomly to another position, etc. The time the target remained at each position was randomized (according to a uniform distribution of values) over the interval of 1.0 to 1.75 s. This was the same target movement sequence used in our ocular tracking study (3). The moving targets provided a pure motion cue; target intensity remained constant. The fixed-position targets were presented intermittently; they were turned on for 0.5 s, then extinguished for a random interval of 0.5 to 1.25 s. This preserved the same overall timing as in the moving-target conditions. The fixed targets provided a pure "onset" cue without movement; these targets were presented at the center of the display. The seven subjects were tested five times (trials) under each of the four conditions on nonconsecutive days. The order of presentation of the conditions was randomized for each subject and trial. A total of 2,800 responses were recorded under each condition (7 subjects  $\times$  5 trials  $\times$  80 presentations).

**Data Analysis:** The RT data were screened for aberrant responses by discarding any values less than 75 ms or greater than 500 ms. Responses less than 75 ms were considered not stimulus related; responses after 500 ms were attributed to inattention on the part of the subject. Usually, only 2 or 3 values were discarded, and in no case were more than 8 of the 80 responses discarded from any trial. The RT values were then averaged for each target movement step size for the moving-target conditions and averaged overall for the fixed-target conditions. The functional dependence of RT on target movement step size was then determined. A second-order polynomial regression of RT on target movement amplitude was performed and the linear and quadratic coefficients were tested against zero. If either of these coefficients were statistically different from zero, then RT was considered to be dependent on target movement amplitude. RT was found to decrease significantly with target-movement amplitude for the MAT; both the linear and quadratic coefficients were nonzero. MVT responses did not demonstrate dependency on target movement. Since the MVT responses were not a function of target movement amplitude, RT was averaged overall. Thus, the MVT, FVT, and FAT conditions each yielded a single average RT value per trial, but the

# REACTION TIME ANALYSIS—ENGELKEN ET AL.

MAT condition resulted in average RT as a function of target movement amplitude. The MVT, FVT, and FAT conditions were compared using the paired *t*-test, where pairing was on subjects and each data value was average RT over the five trials. Comparisons to the MAT condition were made using average RT for each target movement size.

## RESULTS

A summary of the RT data is presented graphically in Fig. 1 and numerically in Table I. The statistical analysis of the RT data is given in Table II.

## DISCUSSION

The most interesting finding of this study was the strong dissimilarity between the responses to fixed and moving auditory targets. In the case of the FAT the subjects responded to the onset of the sound; no auditory localization was required. By contrast, the constant intensity MAT provided only a motion cue and some degree of auditory localization was required to detect the motion. We found that sound onset detection was accomplished from 36 to 35 ms faster than sound-source motion detection. On the other hand, the FVT and MVT responses yielded nearly identical RTs. The slight, but statistically significant, advantage of the MVT (8.4 ms) over the FVT was probably due to the fact that the moving target provided two cues. When the new target light was illuminated the old light was simultaneously extinguished. Extinguishing the old light provided an additional component to the stimulus not present in the FVT condition. Also, the movement placed the target image on a new retinal position, away from the slower responding central area.

The decrease in RT with increasing target movement amplitude for the MAT condition is roughly exponential and looks much like the RT vs. sound level or the RT

TABLE I. REACTION TIME RESULTS.

Condition	Average RT (ms)	S.E.M. (ms)
MVT	233.1	9.2
MAT*	219-268	8.8-10.8
FVT	241.5	7.3
FAT	182.9	4.2

\* RT depends on target movement amplitude, min and max given.

TABLE II. STATISTICAL CONTRASTS, PAIRED *t*-TEST RESULTS.

Comparison	RT Difference (ms)	Significance
MVT-FVT	8.4	$p < 0.05$
MAT-FAT*	36-85	$p < 0.001$
FVT-FAT	58.6	$p < 0.001$
MVT-FAT	50.2	$p < 0.001$

\* RT depends on target movement amplitude, min and max given.

vs. light intensity curves presented by Moody (10). The effect of diminishing RT for increasing stimulus strength is well known and has been observed by others (7,8). The similarity of the MAT responses to these previously reported results suggests that target movement amplitude corresponds to stimulus strength in the MAT condition. We postulate that larger target movements cause greater changes in the interaural time and intensity cues used to detect motion; and therefore, the large movements constitute stronger stimuli resulting in shorter RTs. We believe the same process contributes significantly to the dependence of saccadic latency on target movement amplitude when visually tracking auditory targets.

Executing eye movements in order to track a moving sound source requires both detection of the sound-source movement and localization of the sound source. By measuring simple RT using a key-pressing task we have separately studied the sound-source motion detection process. As shown in Fig. 2, key-pressing RT and saccade latency for auditory targets have a similar functional dependence on target movement amplitude.

We also demonstrated that RT is much shorter for sound onset detection than for sound-source motion detection. We conclude that the latency difference between visual and auditory saccades is due, at least in part, to the sound-source motion detection process.

Our findings differ from those obtained in a previously reported study. Zambbarbieri, *et al.* (15) measured key-pressing RT responses using the same moving targets employed in their ocular tracking studies. They reported no dependence of RT on target movement amplitude for auditory targets and obtained significantly shorter RTs for auditory targets than for visual. However, in their MAT trials, they used sounds that "popped on" at each target position providing an onset cue. The subjects in their key-pressing trials were obviously responding to sound onset, not to the sound-source movement or location cues. Failure to account for this fact resulted in their conclusion that increased saccade latency for the auditory targets was solely a result of increased processing time needed to localize the targets. By keeping sound intensity constant in our

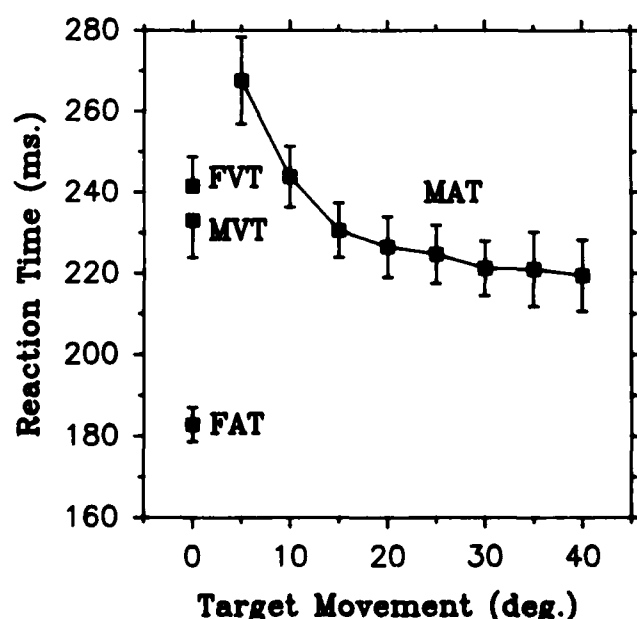


Fig. 1. Results of the reaction-time study. Overall means and standard errors of the means are presented for each of the four test conditions.

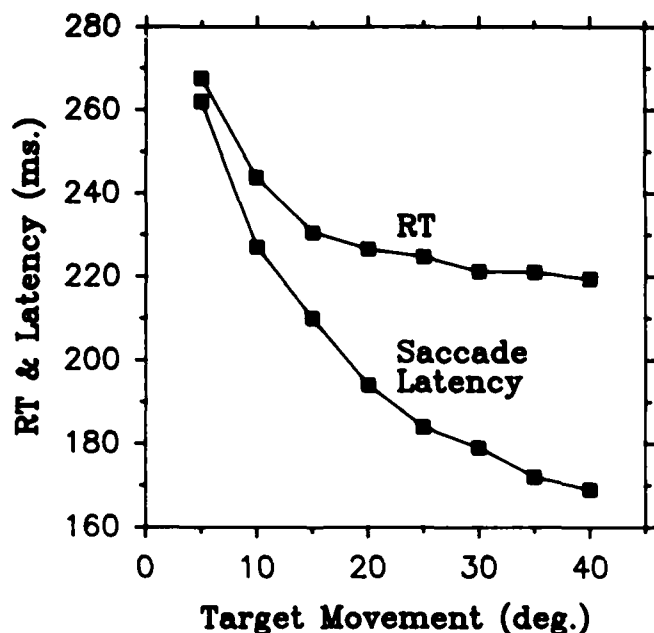


Fig. 2. Reaction-time responses for the MAT condition are compared to the saccade latency results from a previous study. In both cases the subjects responded to a constant-intensity, moving auditory target that provided only movement and localization cues. Both RT and saccade latency decrease with increasing target movement amplitude.

MAT trials, we have shown that the increased time required for sound-source motion detection is a significant factor in explaining these differences.

The use of simulated audio cues to convey spatial information to a pilot in the cockpit has been proposed (1,2). One attractive feature of the auditory system is that, compared to the visual system, audition is generally considered more resistant to the effects of hypoxia, and hence more robust in a high-G environment. We have shown that sound-source motion detection is a much slower process than sound-onset detection. This implies that auditory motion detection (and localization) are more complex sensory processing tasks, and therefore, may not be as robust as simple sound detection. Unfortunately, there is little information available about auditory function (sound detection or localization) at high-G or during hypoxia.

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